

ENERGY DISSIPATORS FOR FLUMES AND CULVERTS



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ENERGY DISSIPATORS FOR FLUMES AND CULVERTS

by

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ABSTRACT

New forest roads constructed in mountainous terrain typically block established drainage channels, and soil erosion can occur as new runoff patterns are established. To prevent this, flumes and culverts are installed along the new road bed. The energy of the concentrated flows from the drainage structures then has to be dissipated, or heavy erosion will take place at the outlets of these devices.

After investigating the state-of-the-art of such energy dissipators, the San Dimas Equipment Development Center (SDEDC) initiated a program to develop practical dissipators for forest use. Field tests indicate that the developed design will do the job at sites rated less than "severe" and that the approach of placing rock "rip-rap" at flume and culvert outlets can also be a viable way of mitigating the negative effects of concentrated discharge flows.

KEY WORDS: Erosion control, runoff water energy dissipation, drainage structures/devices, flumes and culverts, (rock) rip-rap.

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INTRODUCTION

When new roads are constructed in mountainous terrain, they block established drainage channels. This changes the existing runoff patterns and causes new erosion. Ofttimes soil carried away by this erosion will cause sediment transport in previously clear streams. Forest Service engineers, in an attempt to protect newly constructed roads and to counter the negative aspects of newly forming runoff patterns, typically will specify the installation of flumes, culvert cross drains, overside drains, or special drainage structures. However, these specified flumes and culverts concentrate the flows, and previously stable terrain can be upset, causing erosion to occur at the outlets of these devices.

In an attempt to dissipate the energy of the water carried by specified drainage devices and thus reduce the potential for erosion, engineers have placed rocks, concrete posts, or similar material ("rip-rap") at the outlets of the flumes and culverts. Usually the material for these rip-rap sites (fig. 1) has to be imported and the ground at the outlet has to be trenched out to hold the material. The material is then placed, frequently by hand, in a very irregular manner in an attempt to interrupt and deflect water flow and spread the flow stream. These efforts are often frustrated because either the rip-rap itself is washed away or sediment, carried by the water flow, is deposited at the rip-rap site, causing the rip-rap to be less irregular, thus reducing its energy dissipating capability.



Figure 1. Typical rip-rap site, Toiyabe National Forest, Calif.

Road failures caused by erosion at the outlets of flumes and culverts, coupled with often futile attempts to eliminate this cause of erosion, resulted in a project being assigned to SDEDC to investigate possible solutions to these problems.

EROSION CONTROL INFORMATION SEARCH

First, SDEDC contacted road engineers throughout the Forest Service to find out what on-the-ground people felt was needed. Their responses were reviewed, grouped, and summarized as working criteria. Second, a dozen universities throughout the United States (plus one from Brazil), several hydraulic research organizations, a professional society (the American Society of Civil Engineers), and other agencies having problems similar to the Forest Service were contacted to ascertain the status of their research and development efforts. None of these organizations had a solution to the particular problems facing our engineers. Third, all available literature on the problem was reviewed. The literature search uncovered two energy dissipators for small culverts that were currently being used: one by South Dakota, the other by Missouri. Neither seemed to present an overall solution to the Forest Service's problem.

The field survey of Forest Service units resulted in the following working criteria for an energy dissipator for flumes and culverts:

- Should be self-cleaning as to debris (rocks, soil, brush, limbs, etc.); at a minimum, must be designed so that manual cleaning can be performed.
- Must be designed so that either the complete unit or each of its component parts is lightweight enough to be hand-carried.
- Must be self-anchoring, and not depend on the flume or culvert for support.
- Should be fabricated from an inexpensive metal that is readily available nationally and is abrasion and impact resistant to rocks, up to 6 in, carried in the water stream.
- Should be designed so that parts subject to very heavy abrasion and impact can be easily replaced.
- Should be designed for culverts on slopes up to 67 percent.
- Should be designed for water flows having specific energies up to 10 ft of head at the entrance of the culvert.

DISSIPATOR DESIGN, DEVELOPMENT, AND TEST

Since the search efforts failed to uncover energy dissipators capable of specifically solving the Forest Service's problems, the Bureau of Reclamation at Denver, Colo., was asked to

design a 10-in model of a totally new "basic" energy dissipator. ^{1/} The Bureau was to design and study a dissipator model that would satisfy the requirements of SDEDC's criteria list.

A full-size dissipator, fabricated by scaling up the Bureau's design (fig. 2) was tested by SDEDC engineers in the bed of the San Gabriel River on the Angeles National Forest, Calif. The results looked promising; it was effective at reducing flow energy and exhibited self-cleaning action, even for rocks up to 8 in in diameter. Fabrication of 20 of these dissipators proceeded at SDEDC, and Forest Service Regions were asked to select locations for dissipator placement.



Figure 2. Energy dissipator based on results of hydraulic model studies.

Selection of Test Sites

Every site selected either had an actual erosion problem or was thought to be a potential erosion location, so all site descriptors used in this report are relative terms. Some of the sites (Lolo National Forest, Mont., for example) selected were very "severe," being on the side of steep fill slopes where the soil was unstable and the fill material was new and loose (figs. 3 and 4). Other sites (e.g., Ozark National Forest, Ark.) were less severe, with bottoms of fill slopes where the soil was relatively stable (figs. 5 and 6). The Bureau dissipators were installed in seven Forest Service Regions. Because a hole larger than the size of the dissipator had to be excavated, the area right at the dissipator lip consisted of freshly loosened soil. Unless this soil was very cohesive, this area was usually filled with available rock. In three of the Regions, hand-placed rock rip-rap (instead of a dissipator) was placed at the outlet of pipe culverts so that comparative data on two approaches to energy dissipation could be gathered.

^{1/} Colgate, D. 1971. Hydraulic model studies of corrugated-metal pipe underdrain energy dissipators. REC-ERC-71-10. Bureau of Reclamation, Denver, Colo.



Figure 3. Dissipator installed at "severe" location.

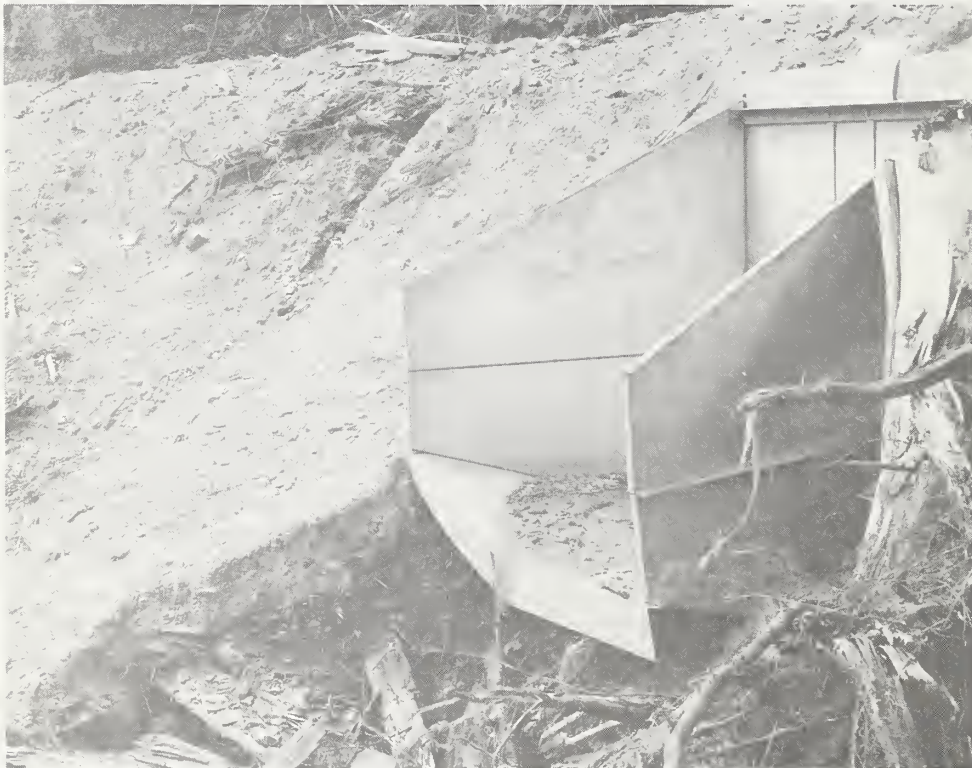


Figure 4. "Severe" site shows signs of much erosion.



Figure 5. Dissipator right after being installed at relatively "stable" site.



Figure 6. Dissipator has successfully stemmed erosion at the "stable" site.

Field Test Results

The success of a dissipator at any particular test site depended on the severity of the location. The following table briefly describes all the 20 test sites that were used, the installation facts, and the results observed during inspection visits. To obtain recordings of flow rates through the dissipators as a function of time, a battery-operated, flow-actuated recorder was innovated to instrument several of the installed dissipators. The flow data noted in the table are summaries of records taken by these instruments.

The average 1970 cost of hand-placed rip-rap at the test sites discussed in this report was \$370. The average cost of an 18-in dissipator, installed, was \$365. Rip-rap costs varied from \$150 to \$590, depending on the amount of rip-rap and its availability. The cost of materials and labor to build and install a dissipator only varied about 20 percent, from \$325 to \$390. Since both dissipators and hand-placed rock rip-rap dissipate energy, the choice of which to use will depend on the cost, availability, and quantity of rip-rap needed. The quantity of rip-rap used during these tests varied from 8 to 35 cu yd.

AVAILABLE DESIGN PACKAGE

A comprehensive design/installation information package pertaining to the Bureau's design, available upon request to SDEDC, can be used to fabricate and install flume and culvert energy dissipators. The package includes two drawings that provide dimensions for a basic 18-in dissipator. One drawing is to be used for culverts having up to 40 percent pipe slope; the other is for pipe slopes of 40 percent and over. To design dissipators for use on flumes and culverts where the flow requires a dissipator to be sized differently than the basic one, a dimension factor chart is provided.

CONCLUSIONS

How successful a dissipator is at reducing erosion is dependent on the severity of the site. When the proper design is utilized, the performance of an energy dissipator is independent of the pipe slope. An energy dissipator is self-cleaning of sediment so long as the flow rate occasionally exceeds 15 percent of the dissipator's flow rating and the flow has an opportunity to continue downstream.

Hand-placed rock rip-rap can also effectively dissipate the energy of water flowing from flumes and culverts. A well-done job is about as expensive as the complete cost of dissipator fabrication and installation; it can be more expensive if large quantities of rock must be hauled for long distances.

Field tests of SDEDC-fabricated energy dissipators

Site No.	Site Location and Initial Installation Date	Site Description	Installation Description	INSPECTION RESULTS		
				Sediment	Erosion	Comments
1	Willamette Nat'l Forest, Ore. October 1969.	Unstable soil; discharge onto old fill slope.	18-in dissipator with 4 ft of rock rip-rap beyond dissipator lip. (Not a very good installation; should have been recessed more into fill slope.)	Some, but not a problem.	None visually apparent.	Very successful installation at a severe site. Over a 6-month period a recorder showed a total water flow of about 10 acre-ft (over half of this in a 1-month span) and a maximum flow of 3 cfs.
2	Willamette Nat'l Forest, Ore. October 1969.	Unstable soil; discharge onto new, loose fill slope.	18-in dissipator with over 1 ft of rock rip-rap beyond dissipator lip.	N/A	See comments.	By summer of 1970 there was considerable erosion; a lot of soil had been washed out from under dissipator by a small spring. By summer of 1971 dissipator had failed.
3	Willamette Nat'l Forest, Ore. October 1969.	Unstable soil; discharge onto old fill slope.	Hand-placed rock rip-rap.	Not a problem.	None visually apparent.	No visual change in this site from October 1969 to September 1975.
4	Toiyabe Nat'l Forest, Nev. October 1969.	Stable soil; discharge onto old fill slope.	18-in dissipator with 2 ft of rock rip-rap beyond dissipator lip. Site repaired; this time 6-in minus rock placed at dissipator lip: September 1971.	Some, but not a problem.	Only a little (3 to 4 in).	During the first 2 yr this site stabilized well; brush and grass grew at dissipator lip. Then a flash flood caused a mud slide which badly damaged the dissipator.
5	Toiyabe Nat'l Forest, Nev. October 1969.	Stable soil; discharge at base of fill onto firm natural ground on a mild slope.	Hand-placed rock rip-rap. Rocks were 25 to 150 lb, with more than half over 75 lb; for a total of 35 cu yd.	Not a problem.	None.	Seven storms occurred in one 10-month period with a total measured flow of 106 acre-ft. The maximum recorded flow was 12 cfs.
6	Ozark Nat'l Forest, Ark. July 1970.	Unstable soil; discharge onto new, loose fill slope near top of high fill. Relocated to site with stable soil; discharge onto very steep (~60%) natural slope: June 1971.	24-in dissipator with 4 ft of rock rip-rap beyond dissipator lip. Same, just as above.	N/A	See comments.	By 1975 brush, grass, and weeds were growing in and through the rip-rap; the site is becoming difficult to identify. Day after installation, site hit by hurricane that partly washed out dissipator along with about 450 cu yd of new fill material.

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Field tests of SDEDC-fabricated energy dissipators

Site No.	Site Location and Initial Installation Date	Site Description	Installation Description	INSPECTION RESULTS		
				Sediment	Erosion	Comments
7	Ozark Nat'l Forest, Ark. July 1970.	Stable soil; discharge onto firm, natural ground at base of fill.	18-in dissipator.	Quickly silted almost full, but not a problem.	Very little—none apparent after first year. After second year small 6-in deep channel visible about 5 ft downstream of dissipator lip; after 5 yr the small channel had worked back to lip.	Flow recorder showed over 14 small storms, with runoff through the dissipator measuring 7.4 acre-ft at a peak flow of 2.3 cfs.
8 & 9	CANCELED.					
10	San Bernardino Nat'l Forest, Calif. May 1970.	Unstable soil; discharge onto natural soil at base of fill.	18-in dissipator.	Silted almost full by end of first year, but not a problem.	Moderate—after 5 yr small channel, 3 ft wide by 1 ft deep, visible.	None.
11	San Bernardino Nat'l Forest, Calif. May 1970.	Unstable soil; discharge onto natural soil at base of fill.	18-in dissipator.	Silted full; potential of pipe becoming plugged.	None.	A 3% rise in the channel just downstream of the dissipator lip caused a silting problem, so dissipator was removed after 1 yr.
12	San Bernardino Nat'l Forest, Calif. May 1970.	Unstable soil; discharge onto new, loose fill (filling eroded hole) at base of fill.	18-in dissipator with about 1 ft of rock rip-rap beyond dissipator lip. Repaired by filling eroded hole with 6-in minus rock: August 1971.	Only a little. Same, just as above.	A lot: see comments. Only a little: see comments.	During first year, all the soil washed out from under the rip-rap, leaving a 5-ft wide by 6-ft deep hole with a 3- to 4-ft wide by 4-ft deep channel leading out of it. Rock settled 4 to 5 in; then the site stabilized.
13	Coconino Nat'l Forest, Ariz. July 1970.	Unstable soil; discharge onto new, loose fill slope.	18-in dissipator.	Silted almost full since Sept. 1970, but not a problem.	A 6-ft wide by about 1-ft deep channel formed in Sept. 1970; see comments.	On September 5, 1970, a heavy rain fell in the area (3 to 7 in) over a 14-hr period and, since this culvert carries runoff from a 14-acre area, dissipator experienced high flows. After storm, site established—by May 1975 brush and grass growing in and around channel.

14	Coconino Nat'l Forest, Ariz. July 1970.	Unstable soil; discharge onto new, loose fill slope.	Hand-placed rock rip-rap. Used 8 cu yd of hand-selected fractured rock.	None visually apparent.	None visually apparent.	In May 1975 this site looked almost exactly the same as when rip-rap installed, with a little vegetation growing in the rip-rapped area.
15	Coconino Nat'l Forest, Ariz. July 1970.	Unstable soil; discharge onto new, very loose fill material.	18-in dissipator with over 1 ft of rock rip-rap beyond dissipator lip. (Not a good installation; should have been recessed more into fill slope.)	N/A	Heavy: see comments.	The previously mentioned Sept. 5, 1970, storm completely undermined the dissipator.
16	Arapaho Nat'l Forest, Colo. August 1971.	Relocated to site with stable soil; discharge onto natural ground at base of fill: May 1973.	Same, just as above: except used 2 ft of rock rip-rap.	Quickly silted almost full, but not a problem.	None visually apparent.	Very little change at new site during 2 yr following the relocation.
17	Arapaho Nat'l Forest, Colo. August 1971.	Stable soil; discharge onto natural ground at base of fill.	18-in dissipator with 3 ft of rock rip-rap beyond dissipator lip.	Silted almost full by end of first year, but not a problem.	None visually apparent.	Some water seen flowing through dissipator during each inspection.
18	Boise Nat'l Forest, Idaho. August 1970.	Stable soil; discharge onto natural ground at base of fill.	18-in dissipator.	Silted almost full by end of first year, but not a problem.	Only a little (about 3 in).	None.
19	CANCELED.	Slightly unstable soil; discharge onto natural ground at base of fill.	18-in dissipator.	Silted almost full by end of first year, but not a problem.	A 2-ft wide by 8- to 10-in deep channel formed during the first year.	Flow recorder indicated 94 acre-ft of runoff in a 5-day period, with a peak flow of more than 14 cfs. Flows from 0.1 to 0.8 cfs occur regularly at this site, averaging just about 0.5 cfs. This site probably experienced a higher total flow than any other test site.
20	Lolo Nat'l Forest, Mont. October 1970.	6-in minus rock placed in eroded channel: October 1971.	18-in dissipator.	None.	None.	Good growth of vegetation in and around channel.
		Unstable soil; discharge onto new, loose fill slope.	18-in dissipator with about 2-ft of rock rip-rap beyond dissipator lip.	N/A	See comments.	After the first year it became obvious that this was a very poor site. The dissipator had been inadvertently installed on a pile of slash; the loose soil about the pile got washed away.
		Relocated to site with stable soil; discharge onto natural ground at base of fill: June 1973.	18-in dissipator with about 2-ft of rock rip-rap beyond dissipator lip.	None first year; in 1975 dissipator had silt, but not a problem.	Very little.	The new site experienced flows year around. At time of first year inspection, a high-water period, flows of about 4 cfs were observed and, while there was no silt in dissipator, there was some gravel present. In 1975, flows of 0.5 to 1.0 cfs were recorded.

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INSPECTION RESULTS

Site No.	Site Location and Initial Installation Date	Site Description	Installation Description	Sediment	Erosion	Comments
21	Li Jo Nat'l Forest, Mont. October 1970.	Unstable soil; discharge onto new loose fill slope.	24-in dissipator.	See comments.	See comments.	By the end of the first year the dissipator had been destroyed by a landslide.
22	Mendocino Nat'l Forest, Calif. October 1972.	Unstable soil; discharge onto new, loose fill (filling eroded hole) at base of fill.	18-in dissipator.	Silted about half full by end of first year, but not a problem.	A 2½-ft wide by 1-ft deep channel formed by end of first year.	Since end of first year, when small channel eroded, there has been no visually apparent change, even though rainfall was double normal in 1974.
23	Angeles Nat'l Forest, Calif. January 1973.	Unstable soil; discharge at base of spillway of small earth-fill check dam.	18-in dissipator.	Silted full, but not a problem.	None.	Maximum flow, based on high-water mark on spillway of check dam, exceeded 20 cfs in one storm. People tossed electrical conduit, rags, tires, boards, etc. into the dissipator and this material had to be removed since it could not pass under the dissipator baffle.